Universiti Malaysia PAHANG
Engineering • Technology • Creativity

SUPERVISOR's DECLARATION

I/We* hereby declare that I/We* have checked this thesis/project* and in my/our* opinion, this thesis/project* is adequate in terms of scope and quality for the award of the degree of Manufacturing Engineering.

(Supervisor's Signature)

Full Name : DR.MUHAMMED NAFIS BIN OSMAN ZAHID

Position :

Date : 7/6/17

DR. MUHAMMED NAFIS BIN OSMAN ZAHID
PENSYARAH KANAN
FAKULTI KEJURUTERAAN PEMBUATAN
UNIVERSITI MALAYSIA PAHANG
26600 PEKAN
PAHANG DARUL MAKMUR
Tel: +609-424 5917 Faks: +609-424 5888

(Co-supervisor's Signature)

Full Name :

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_____

(Student's Signature)

Full Name : SITI NORHANANI BT SAARI

ID Number : FA13013

Date : 7 JUNE 2017

CUTTING ORIENTATIONS OF NON-COMPLEX PARTS IN 4TH AXIS CNC MACHINING FOR RAPID MANUFACTURING PROCESSES

SITI NORHANANI BT SAARI

Thesis submitted in fulfilment of the requirements

for the award of the degree of

Manufacturing Engineering

Faculty of Manufacturing Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2017

ACKNOWLEDGEMENTS

In the name of Allah, Most Gracious, Most Merciful. I thank Allah for granting me the perseverance and strengths during the completion of this thesis.

I am grateful and would like to express my sincere gratitude to my supervisor Dr.Muhammed Nafis Bin Osman Zahid for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a PhD program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career. I also would like to express very special thanks to my co-supervisor En.Hafiz, Dr Nafis master's student, for his suggestions and co-operation throughout the study. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my lab mates and members of the staff of the Manufacturing Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to member engine research group for their excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I acknowledge my gratefully thanks would goes to my friends, for always giving me their endless co-operatives by helping me and spending his time to correct my mistakes. I would like thank to all my batch mates that have been providing me a really pleasant condition to helping me accomplishing my project thesis

ABSTRAK

Memandangkan tempoh masa dan kos yang diperlukan manakala menghasilkan bahagian-bahagian atau produk menjejaskan pengeluaran dan pelanggan kepuasan. Rapid Manufacturing boleh disesuaikan dengan menggunakan komputer kawalan berangka (CNC) yang merupakan salah satu kaedah pengilangan. Kebolehcapaian alat boleh meningkatkan menggunakan 3-axis CNC Mesin pengilangan dengan alat pengindeksan dan boleh mengatasi sebahagian besar daripada kekangan proses. Ketika membuat operasi untuk mencari orientasi memotong optimum, lebih banyak kerja yang diperlukan untuk mencipta satu demi satu orientasi dengan nilai memotong orientasi diperlukan. Jadi, perlu membuat GUI untuk memastikan nilai kunci orientasi dalam mudah untuk membuat pembedahan. karya ini memberi tumpuan dalam mencari orientasi pemotongan optimum dan untuk menganalisis implikasi orientasi ke arah masa pemesinan. Dengan membuat antara muka, masa operasi dapat dikurangkan dan mudah untuk mencari operasi pemotongan optimum. RM rapat berkaitan dengan masa tetapi pasti perlu mengambil kira kepuasan pelanggan. Dalam menganalisis implikasi orientasi ke arah masa pemesinan. Setiap orientasi akan memberi kesan kepada masa pemesinan yang bergantung kepada geometri model maju.

Kemajuan Manufacturing Berbantukan Komputer (CAM) dieksploitasi dalam merealisasikan sistem pemesinan pesat. Ini membolehkan perancangan proses CNC yang akan dikendalikan melalui kod pengaturcaraan disesuaikan. Penemuan daripada kajian simulasi disokong oleh keputusan pemesinan eksperimen. Orientasi roughing adalah tetap untuk semua operasi awal model. Orientasi roughing dikurangkan masa pemotongan dan mengurangkan kerja-kerja operasi penamat. Kemasan operasi akan memberikan hasil yang terbaik bahagian akhir. Orientasi optimum berkaitan dengan bahagian geometri.

ABSTRACT

Considering time frame and cost needed while producing the parts or product affecting the production and customer satisfaction. Rapid Manufacturing can be adapted by using Computer Numerical Controlled (CNC) which is one of the methods in manufacturing. The tool accessibility can be increasing using 3-axis CNC milling machine with an indexing device and can overcomes most of the process constraints. While make an operation to finding the optimum cutting orientations, more work is required to create one by one orientation with the value of cutting orientation needed. So, need to make GUI to ensure the values of orientations key in are easy to make an operation. This thesis focuses on finding the optimum cutting orientation and to analyse the implication of orientation towards machining time. With making interface, the operation time can be reduced and easy to find the optimum cutting operation. RM is closely related with time but surely need to consider customer satisfaction. In analyses the implication of orientation towards machining time. Every orientation will give effect to the machining time which depends on the geometry of the models developed.

The advancement of Computer Aided Manufacturing (CAM) is exploited in realising a rapid machining system. This allows CNC process planning to be handled through customised programming codes. The findings from simulation studies are supported by the machining experiment results. The roughing orientations are fixed for all earlier operation of the models. The roughing orientations minimized the cutting time and decreasing the finishing operation work. Finishing operation will give the best result of part finish. The optimum orientation relate with part geometries.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentages
°	Angles
mm	millimetres
θ	Input angle
mmpm	Millimetres per minute
Ø	Diameter
rpm	Revolution per minute

LIST OF ABBREVIATIONS

AM	Additive manufacturing
ArcHLM	Arc hybrid-layered manufacturing
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CNC	Computer Numerical Control
D	Dimension
EBM	Electron Beam Melting
EDM	Electrical Discharge Machine
FDM	Fused Deposition Modelling
GUI	Graphical User Interface
IPW	In-process Workpiece
MCS	Machine Coordinate System
RM	Rapid Manufacturing
RP	Rapid Prototyping
SLA	Stereo lithography
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
ABS	Acrylonitrile Butadiene Styrene
SRP	Subtractive Rapid Prototyping

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In recent years, considering the time frame and cost needed while producing the parts or product is really important and this will affecting the production and customer satisfaction. Based on this characteristics, rapid manufacturing (RP) has high potential to reduce the cost and cycle of product development [1]. In late 1980, in producing models and prototype parts, the first methods for rapid prototyping have been introduced. In rapid prototyping, fabrication of the prototypes or scale model of a physical part or assembly produced in fast way. RP cannot be understood and seen on conventional engineering drawing because mechanical RP scale model allow visualizing complex shape. RP helps engineering student to develop product before become an actual scale. The purpose RP technology is to make analysis of the products and future process in develop the real product. Using this techniques, any changes of the design at early phase can be improved before the producing the real product. RP contribute in medical field which function to build human implants quickly and accurately, procedure of cardiovascular surgical are training using RP models [2] . In producing RP design, a few phase need to pass which to manufacture the prototype scale to actual scale product.

Additive manufacturing is the technique applied in RP which the molten raw material is added layer by layer. Using RP process, metals are not be able to use. But some materials possessed metal properties and have capability to be used in RP process. For example, cam shaft needed the material that possess properties of metals, the suitable material used to make RP for cam shaft was poly (methyl methacrylate) (PMMA). RP can be classified in 4 types, stereo lithography (SL), selective laser sintering (SLR), fused deposition modelling (FDM), laminated object sintering (LMS)[3].

Although currently in specialist application are using RP systems as the finishing part that no need to manufacture as the real part and will facing many problems to be solved. Rapid manufacturing (RM) is the predecessors of RP and rapid tooling (RT) which has grown in recent years. RM means making finishing part quickly by manufacturing method. Specifically, RM means development of the part that are used directly as finished product using computer aided design (CAD)-based automated additive manufacturing process. RM can be classified into 2 types which are additive manufacturing (AM) and subtractive manufacturing (SM). For AM, development of the part layer by layer compared to SM which need to remove the material from a raw material to form a desired product. AM have ability to construct complex shape than SM[4]. In production, RM is one alternatives that will satisfy customer needed and the development followed the time frame.

AM techniques have been introduced for more than 20 years but limited to the porous structures and prototypes in rapid manufacturing. AM technologies commonly using wire or powder as a feedstock which will melting when heat sources focusing and consolidate subsequent cooling to form a part [5]. Speed in develop manufacturing process is the main constraints and the amount of time consumed effected in fabricating the parts. Besides that, application of manufacturing area expanded to foods, sports, architectural, biomedical product, and aviation which developed in AM field Major advantages of AM compared with subtractive manufacturing, firstly, freeform fabrication allowed in AM process. Providing freeform design for innovative product by removing the traditional manufacturing restrictions. Secondly, AM can decreasing the supply chain fabrication and develop the profits space for manufacturers. Thirdly, environment impact has high potential to be reduce in applying AM technologies [6].

For RM application, CNC machine is one of the reliable techniques. The automatic capabilities of cutting machine like milling, laser cutting and high speed milling are improved by CNC technology [7].In CNC systems, computer aided design (CAD) and computer aided manufacturing (CAM) are used in generating finishing component design. CNC technology have been classified as SM process and brought the technology to an advance phase. In producing complex part of production, CNC machining is widely use such as die-moulds, impellers, turbines and numerous aerospace components. With attaching indexer on CNC machining will have 4th

axis machine and enable to machine parts from various cutting directions. Complex shape can be develop when machining from different orientations and can access at all region of the parts.

1.2 PROBLEM STATEMENT

Traditional CNC machining process involve human in controlling and run the operations. But for RM tools such as AM processes will reducing the human involvement which is the processes will fully automated while production. In addition, rapid manufacturing processes are fully automated by CNC machine and the processing need to consider the timeframe and cost. Manufacturers come out with an idea in producing the parts in rapid manufacturing which need the product to manufacture in fast way and the amount of time used can be compare with the previous method like rapid prototyping. Actually, the higher the number of the orientations, the higher the complexity of the products that can be produced.

In making the CNC machine used in 4^{th} axis machining, indexer is attached at CNC machine that allow the work piece to be rotated to various orientations. The region accessibility to the cutting tool is increasing. However, for non-complex parts, minimizing the cutting orientations supposedly needed because when using various cutting orientations in producing non-complex parts it will use a large amount of time and costly. There is no method to optimize the cutting orientations for non-complex part for 4^{th} axis. Previous methods are using only operation in producing the part in each cutting orientation. Nowadays, separated of the machining operations are separates into two processes which are roughing and finishing. In roughing operation, the parts of the product machined roughly with the irregular surface and finishing process need to remove the remaining material that do not accessible by roughing operation. Limiting the cutting orientation for finishing process are needed compared for roughing operation which can the various cutting orientation applied to the operation.

To make sure the cutting orientation fully covered machining part is using algorithm which developed to consider the surface visibility of the part from different directions. Finishing phase is the important operation to make sure the tool access to all surfaces that need to machine. Cutting orientation was very important in considering all machined part are removing during the processing.

REFERENCES

[1] A. K. Matta, D. R. Raju, and K. N. S. Suman, "The integration of CAD / CAM and Rapid Prototyping in Product Development : A review," *Mater. Today Proc.*, vol. 2, no. 4–5, pp. 3438–3445, 2015.

[2] A. Ahmad, A. Saber, S. Darmoul, A. Ahmad, K. Saud, and K. Saud, "ScienceDirect Prototyping for Rapid Prototyping for Assembly Training and Validation," *IFAC-PapersOnLine*, vol. 48, no. 3, pp. 412–417, 2015.

[3] V. Jaiganesh and E. Mugilan, "Manufacturing of PMMA Cam Shaft by Rapid Prototyping," *Procedia Eng.*, vol. 97, pp. 2127–2135, 2014.

[4] A. C. De Leon, Q. Chen, N. B. Palaganas, J. O. Palaganas, J. Manapat, and R. C. Advincula, "High performance polymer nanocomposites for additive manufacturing applications," *REACT*, vol. 103, pp. 141–155, 2016.

[5] T. Yamazaki, "Development of A Hybrid Multi-tasking Machine Tool: Integration of Additive Manufacturing Technology with CNC Machining," *Procedia CIRP*, vol. 42, no. Isem Xviii, pp. 81–86, 2016.

[6] Y. Tang, K. Mak, and Y. F. Zhao, "A framework to reduce product environmental impact through design optimization for additive manufacturing," *J. Clean. Prod.*, vol. 137, pp. 1560–1572, 2016.

[7] I. Repository, "Cutting orientations for non-complex parts in 4axis machining," 2016.

[8] K. P. Karunakaran, A. Bernard, S. Suryakumar, L. Dembinski, and G. Taillandier, "Rapid manufacturing of metallic objects," *Rapid Prototyp. J.*, vol. 18, no. 4, pp. 264–280, 2012.

[9] R. Hague, S. Mansour, and N. Saleh, "Material and design considerations for rapid manufacturing," vol. 7543, no. November, 2016.

[10] E. Costa, M. Shiomi, K. Osakada, and T. Laoui, "Rapid manufacturing of metal components by laser forming," vol. 46, pp. 1459–1468, 2006.

[11] R. Paul and S. Anand, "Optimal part orientation in Rapid Manufacturing process for achieving geometric tolerances," *J. Manuf. Syst.*, vol. 30, no. 4, pp. 214–222, 2011.

[12] J. K. S. Nagel and F. W. Liou, "Designing a Modular Rapid Manufacturing Process," *J. Manuf. Sci. Eng.*, vol. 132, no. 6, p. 61006, 2010.

[13] V. Canellidis, J. Giannatsis, and V. Dedoussis, "Computer-Aided Design Efficient parts nesting schemes for improving stereolithography utilization," *Comput. Des.*, vol. 45, no. 5, pp. 875–886, 2013.

[14] Y. Pan and Y. Chen, "Meniscus process optimization for smooth surface fabrication in Stereolithography," *Addit. Manuf.*, pp. 1–13, 2016.

[15] Y. Chen and Y. Chen, "3D Texture Mapping for Rapid Manufacturing 3D Texture Mapping for Rapid Manufacturing," vol. 4360, no. November, 2016.

[16] G. A. Bingham, R. J. M. Hague, C. J. Tuck, A. C. Long, and J. J. Crookston, "Rapid manufactured textiles," vol. 3052, no. November, 2016.

[17] A. Habib and B. Khoda, "Attribute driven process architecture for additive manufacturing," *Robot. Comput. Integr. Manuf.*, vol. 44, no. September 2016, pp. 253–265, 2017.

[18] Y. Zhang, R. K. Gupta, and A. Bernard, "Two-dimensional placement optimization for multi-parts production in additive manufacturing," *Robot. Comput. Integr. Manuf.*, vol. 38, pp. 102–117, 2016.

[19] B. Narayan, A. Garg, and K. Shankhwar, "Empirical investigation of environmental characteristic of 3-D additive manufacturing process based on slice thickness and part orientation," *MEASUREMENT*, vol. 86, pp. 293–300, 2016.

[20] D. Herzog, V. Seyda, E. Wycisk, and C. Emmelmann, "Acta Materialia Additive manufacturing of metals," *Acta Mater.*, vol. 117, pp. 371–392, 2016.

[21] S. Ford, "Additive manufacturing and sustainability : an exploratory study of the advantages and challenges," vol. 137, 2016.

[22] C. A. Griffiths, J. Howarth, G. Rowbotham, and A. Rees, "Effect of build parameters on processing efficiency and material performance in fused deposition modelling," *Procedia CIRP*, vol. 49, pp. 28–32, 2016.

[23] A. Boschetto and L. Bottini, "Robotics and Computer-Integrated Manufacturing Design for manufacturing of surfaces to improve accuracy in Fused Deposition Modeling," vol. 37, pp. 103–114, 2016.

[24] J. Singh, R. Singh, and K. Singh, "Parametric optimization of fused deposition modeling and vapour smoothing processes for surface finishing of biomedical implant replicas," vol. 94, pp. 602–613, 2016.

[25] Y. Pan, X. Zhao, C. Zhou, and Y. Chen, "Smooth surface fabrication in mask projection based stereolithography," *J. Manuf. Process.*, vol. 14, no. 4, pp. 460–470, 2012.

[26] P. J. Bartolo and J. Gaspar, "CIRP Annals - Manufacturing Technology Metal filled resin for stereolithography metal part," vol. 57, pp. 235–238, 2008.

[27] F. Liravi, S. Das, and C. Zhou, "Computer-Aided Design Separation force analysis and prediction based on cohesive element model for constrained-surface Stereolithography processes ☆," *Comput. Des.*, vol. 69, pp. 134–142, 2015.

[28] J. Zhou, Z. Lu, K. Miao, and Z. Ji, "Quick fabrication of aeronautical complicated structural parts based on stereolithography," *Propuls. Power Res.*, vol. 4, no. 2, pp. 63–71, 2015.

[29] R. Ganeriwala and T. I. Zohdi, "Multiphysics modeling and simulation of selective laser sintering manufacturing processes," *Procedia CIRP*, vol. 14, pp. 299–304, 2014.

[30] K. Shahzad, J. Deckers, Z. Zhang, J. Kruth, and J. Vleugels, "Additive manufacturing of zirconia parts by indirect selective laser sintering," *J. Eur. Ceram. Soc.*, vol. 34, no. 1, pp.

81–89, 2014.

[31] K. Shahzad, J. Deckers, J. Kruth, and J. Vleugels, "Journal of Materials Processing Technology Additive manufacturing of alumina parts by indirect selective laser sintering and post processing," *J. Mater. Process. Tech.*, vol. 213, no. 9, pp. 1484–1494, 2013.

[32] R. Paul and S. Anand, "Process energy analysis and optimization in selective laser sintering," *J. Manuf. Syst.*, vol. 31, no. 4, pp. 429–437, 2012.

[33] Z. Zhu, V. Dhokia, A. Nassehi, and S. T. Newman, "Investigation of part distortions as a result of hybrid manufacturing," *Robot. Comput. Integr. Manuf.*, vol. 37, pp. 23–32, 2016.

[34] I. Repository, "Computer Numerical Controlled (CNC) machining for Rapid Manufacturing Processes Computer Numerical Controlled (CNC) Machining for Rapid Manufacturing Processes."

[35] D. Watts, "Cutting tools in nishing operations for CNC rapid manufacturing processes : simulation studies," 2014.

[36] J. M. Flynn, A. Shokrani, S. T. Newman, and V. Dhokia, "Hybrid additive and subtractive machine tools - Research and industrial developments," *Int. J. Mach. Tools Manuf.*, vol. 101, pp. 79–101, 2016.

[37] M. V. Nojehdeh and B. Arezoo, "Functional accuracy investigation of work-holding rotary axes in five-axis CNC machine tools," *Int. J. Mach. Tools Manuf.*, vol. 111, pp. 17–30, 2016.

[38] Y. Zhu, Z.-T. Chen, T. Ning, and R.-F. Xu, "Tool orientation optimization for <mml:math altimg='si41.gif' display='inline' overflow='scroll' xmlns:xocs='http://www.elsevier.com/xml/xocs/dtd' xmlns:xs='http://www.w3.org/2001/XMLSchema' xmlns:xsi='http://www.w3.org/2001/XMLSchema-instance' xmlns='," *Comput. Des.*, vol. 77, pp. 60–72, 2016.